Western Pacific Tropical Cyclone Reanalysis with the NRL Atmospheric Variational Data Assimilation System

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LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved initial condition and data assimilation technique. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Due to sparse observational coverage over the open ocean, a key element of typhoon data assimilation is how to assimilate the satellite products such as Advanced Microwave Sounding Unit (AMSU), AIRS, and SSMIS into the model initial condition. These new satellite products provide high-resolution 3-dimessional temperature and moisture fields and rain rate profiles. By assimilating the satellite radiance data, we enhance the NAVDAS capability and thus improve NOGAPS and COAMPS TC and weather forecast.

OBJECTIVES

The objective of this project is to develop a suitable strategy for TC initialization using NAVDAS or WRF 3DVar with application of recently available satellite products and in-situ aircraft observations during TCS-08 field campaign to construct a comprehensive, high-resolution reanalysis dataset for TCs in the western Pacific and provide the dataset to TC community.

APPROACH

Our strategy is to run reanalysis procedures using various observational data including satellite products (e.g., AMSU-A/B brightness temperatures/radiances, scattermeter winds, SSM/I rain rate, polar-orbiter and geostationary feature-track wind), radiosonde, surface land, and flight-level observations, and combine these observations with the COAMPS or WRF model dynamics to retrieve dynamically balanced TC wind, pressure, moisture and temperature fields. We propose to use the NRL NAVDAS and/or WRF 3DVAR assimilation system for 2005-2008 western North Pacific TC cases.

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14. ABSTRACT

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved initial condition and data assimilation technique. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Due to sparse observational coverage over the open ocean, a key element of typhoon data assimilation is how to assimilate the satellite products such as Advanced Microwave Sounding Unit (AMSU), AIRS, and SSMIS into the model initial condition. These new satellite products provide high-resolution 3-dimessional temperature and moisture fields and rain rate profiles. By assimilating the satellite radiance data, we enhance the NAVDAS capability and thus improve NOGAPS and COAMPS TC and weather forecast

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WORK COMPLETED

Collaborating with NRL atmospheric data assimilation team (e.g., Dr. Nancy Baker and Dr. Bill Campbell), we have been improving NAVDAS radiance assimilation techniques using the community radiative transfer model (CRTM). The improvement of satellite (AMSU_B, SSMIS and AIRS) radiance assimilation is crucial for typhoon data assimilation as in the western Pacific open ocean aircraft observations are limited and satellite products are major sources for data assimilation.

A new TC initialization scheme is developed. It overcomes the current 3DVar assimilation problem by including a TC dynamic initialization (TCDI) package. This new initialization scheme has been carefully examined in the observation system simulation experiment (OSSE). Real-case tests of the this new initialization scheme with the NRL operational COAMPS model shows very encouraging results.

Direct aircraft observational data during the 2008 TCS-08 campaign period were collected and used in the western Pacific typhoon reanalysis with the new dynamical initialization scheme.

RESULTS

Most of the current observational systems derive an initial TC condition that has a much weaker intensity than the observed, even though observed TC central minimum pressure has been input into the 3DVar assimilation system. Why do the current operational assimilation systems “reject” the observational data? We analyzed the cause of this problem using the WRF model and its 3DVar system. Regarding the model generated 3D TC as a true state, we conduct an observation system simulation experiment (OSSE) study. We noted that the major problem lies in the background error statistics in 3DVar, which was done in sigma vertical levels while the first guess is given at the standard pressure levels. As a result, a serious error appears when the first guess TC surface pressure field, which is greatly deviated from the true state, is used. Thus, a key aspect of TC initialization is to improve the first guess field prior to 3DVar.

We propose a new TC initialization scheme based on the OSSE. A key ingredient of this scheme is a TC dynamic initialization (TCDI) package consisting of primitive equations with full nonlinear dynamics and physics. Prior to the TCDI, the first guess field is decomposed into a TC vortex and its environmental field. Then we integrate the TCDI forecast model forward and force the first guess vortex toward the observed central minimum pressure (CMP). Meanwhile, a 3D heating field from the “true” state is specified to simulate the asymmetric TC structures. Finally, this asymmetric 3D TC field is embedded into the environmental field to generate the model initial condition.

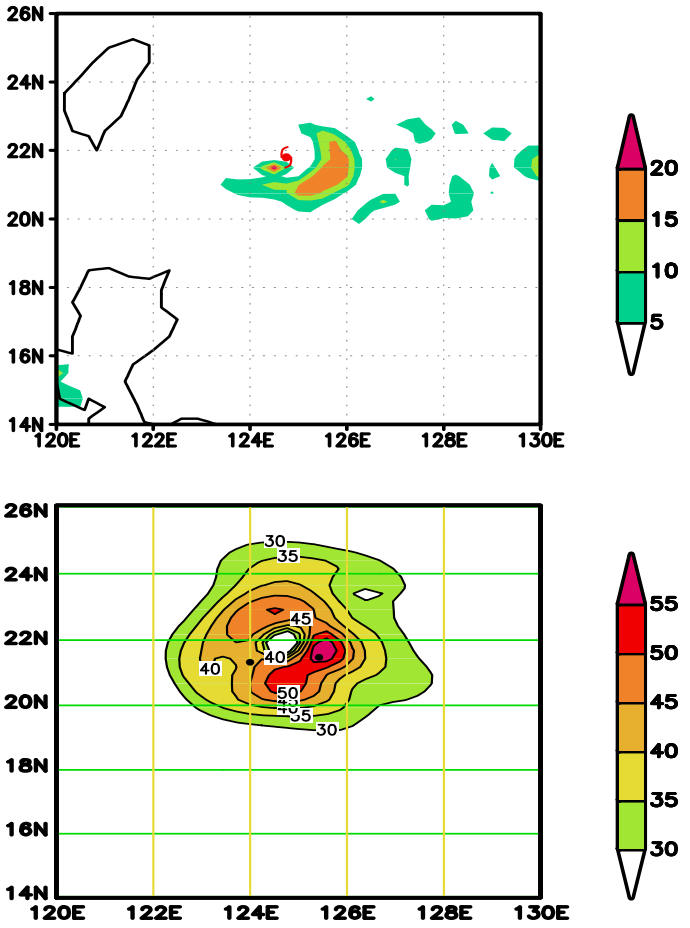

Fig. 1 TCDI/3DVar assimilated wind speed pattern at 850 hPa (bottom panel) and TMI measured 3h accumulated rainfall (top panel) at 1200UTC 11 September 2008.

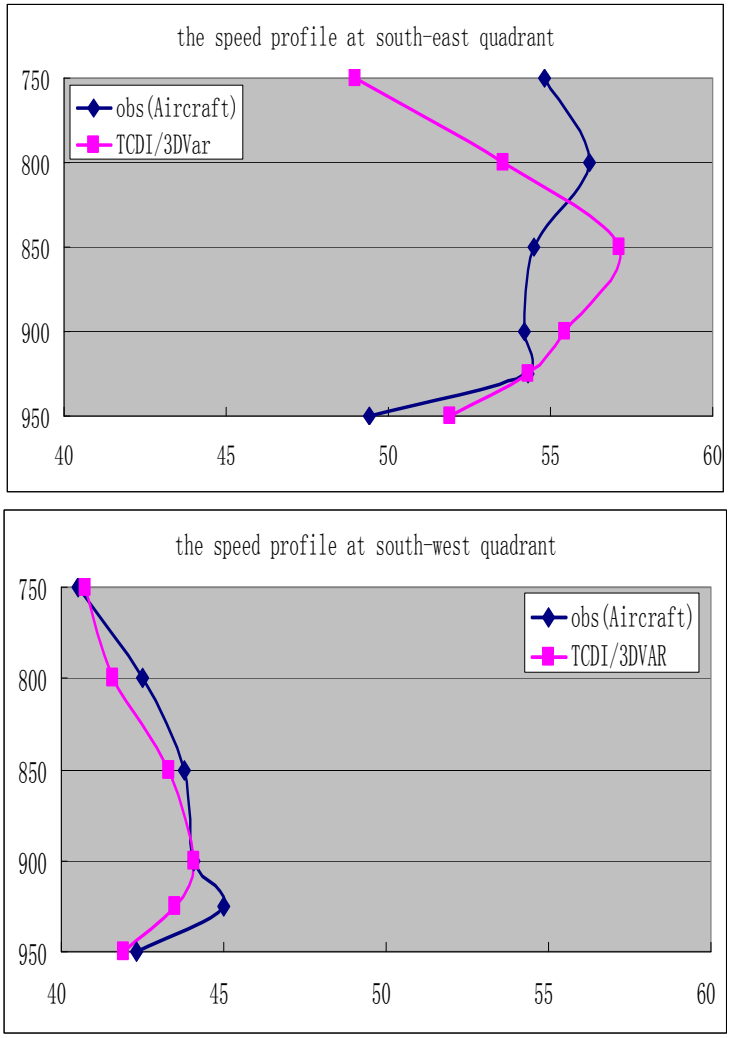

Fig. 2 Vertical profiles of the assimilated and observed wind speed at east (top) and southwest (bottom) of the TC center denoted as a black dot in Fig. 1

To examine the impact of the new initialization scheme, we conducted two parallel experiments. In the first experiment, the TCDI generated new vortex is used as the initial condition. In the second experiment, a simple bogus is specified as the initial condition. The results show that the intensity change with the new initialization scheme is much closer to the "true" evolution. The new initialization scheme is able to capture the observed CMP, upper-level warm core, and asymmetric temperature and wind fields.

The new TC initialization scheme has been applied to real case assimilation during 2005-2008 over western North Pacific. In these real cases, in-situ observations and satellite products are assimilated. The result is very encouraging.

Due to lack of aircraft observations around TC center in western North Pacific, it is difficult to verify the TCDI/3DVar assimilation results. The TCS-08 and TPARC Field Campaign in summer 2008

provided a great opportunity to validate the TCDI/3DVar assimilation results. We have collected available in-situ data such as USAF C-130, NRL P-3 dropsonde data, DLR Falcon Doppler Wind Lidar data, DLR Falcon Flight Level data. We selected Super Typhoon Sinlaku on 11 September 2008 as an example. The TCDI/3DVar assimilation leads to an asymmetric wind field, a maximum wind speed center appears in the east of the typhoon while a relatively weak wind speed appears in the southwest (Fig. 1). This wind asymmetry is consistent with the asymmetry in TRMM rain rate field (Fig. 1). By comparing the wind profiles in the two regions with aircraft observations, we confirm such an asymmetric wind structure (Fig. 2). Using this improved initial condition, we conducted 48h track and intensity forecasts, and the results show that the forecast is improved compared to that without the use of the new initialization scheme.

IMPACT/APPLICATIONS

The application of satellite radiance data assimilation in NAVDAS is critical to improve the NOGAPS and COAMPS predictions of tropical cyclones and weather in general. The new initialization scheme developed here may be applied to real-time operational predictions, leading to the improvement of TC intensity forecast. It may help generate near real-time products of detailed 3D TC structures for disaster estimation and water resource management. The proposed TC reanalysis project will provide valuable datasets for TC research community.

TRANSITIONS

The improved SSMIS, AIRS radiance assimilation codes have been delivered to NRL data assimilation group for further test and possible operational use. The newly developed TC dynamic initialization package will be delivered to NRL after the completion of this project.

RELATED PROJECTS

This project is closely related to the ONR funding entitled “Analysis and high-resolution modeling of tropical cyclogenesis during the TCS-08 and TPARC Field Campaign”. Knowledge gained from this project will help assimilate TCS-08 and TPARC observational data and improve the COAMPS initial condition for TC prediction.

PUBLICATIONS

The following publications are fully or partially supported by this ONR grant:

Ge, X., T. Li, and M. S. Peng, 2009: Cyclogenesis simulations of Typhoon Prapiroon (2000) associated with Rossby wave energy dispersion. Mon.Wea.Rev, in press.

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Manuscript in preparation

Zhang, S., T. Li, X. Ge, and M. S. Peng, 2009: A Combined 3DVar and Tropical Cyclone Dynamic Initialization Scheme.